Jet Propulsion Laboratory
California Institute of Technology

A six year record of OCO-2 XCO_2 measurements

Comparisons against TCCON GGG2014 data

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OCO Science Team Telecon – 27 April, 2021

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Datasets

- Six year record of OCO-2 XCO_2 measurements (V10, Sept. 2014 – Dec. 2020).
- Same time period covered by TCCON with contributions from 28 sites (GGG2014 data record ended in Dec. 2020; no new GGG2014 data from now on).

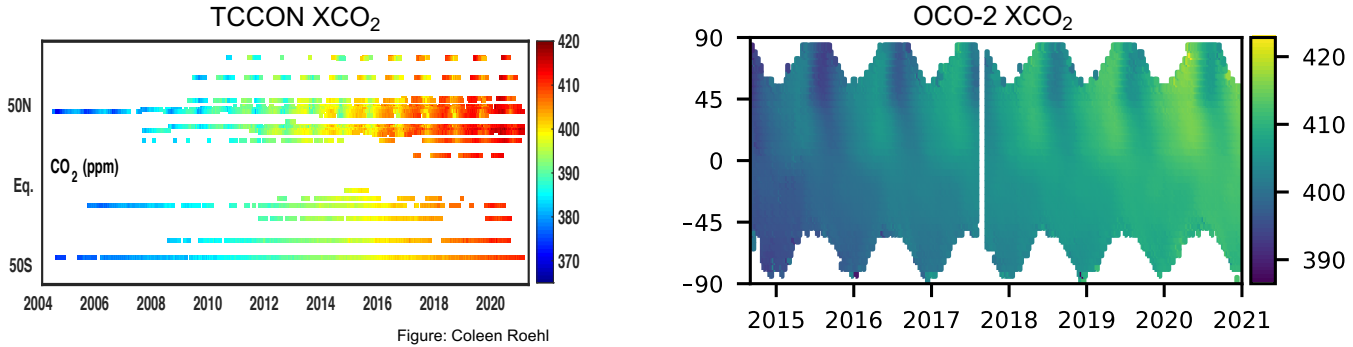
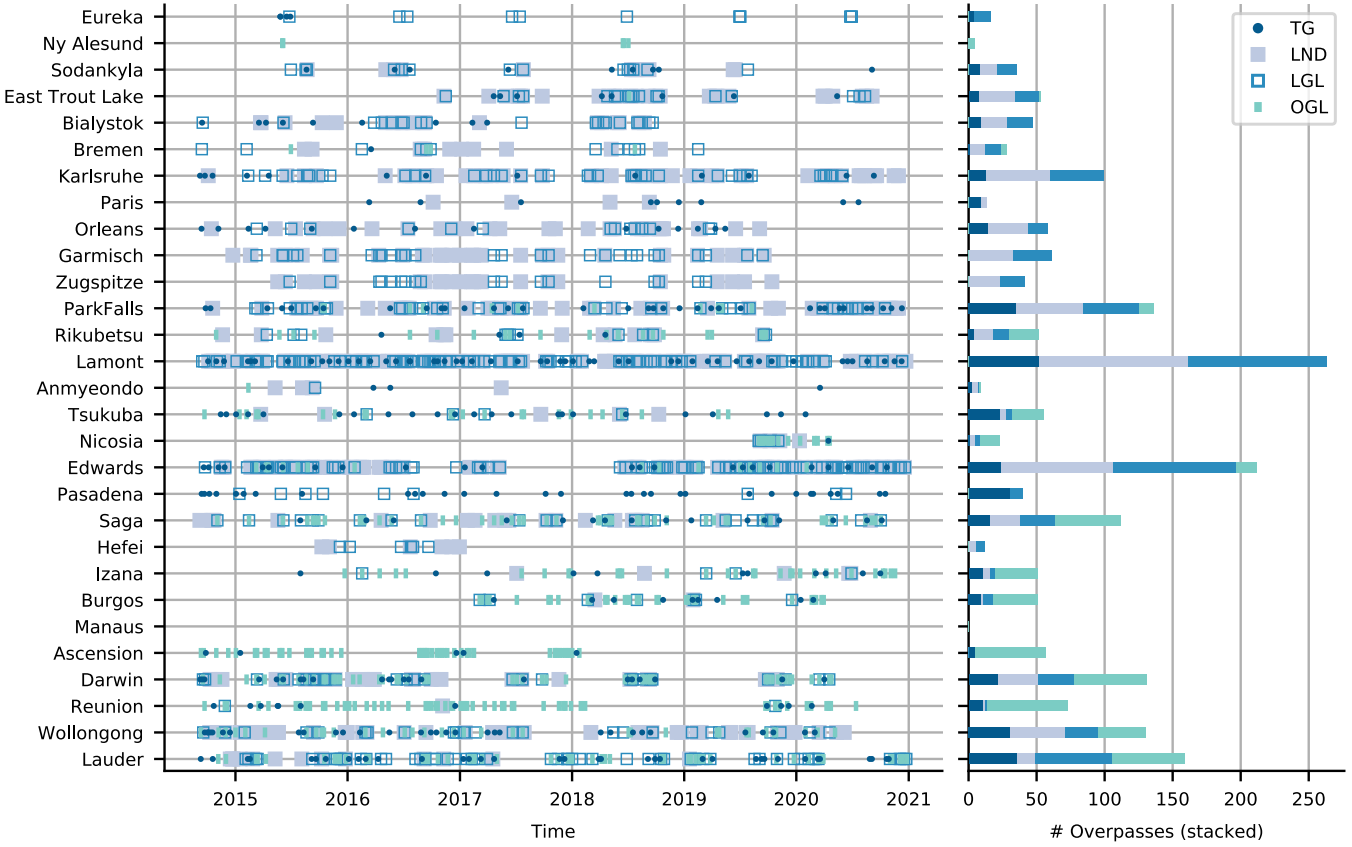


Figure: Coleen Roehl

- We expect good agreement because subset of TCCON data is used for QF/BC development.
- Evaluation of OCO-2 against TCCON with regard to site dependent biases, mode and seasonal dependent biases, trends, mean growth rates, and mean seasonal cycle amplitudes.

Collocation of OCO-2 and TCCON measurements

Geometric collocation criteria for land nadir/glint and ocean glint: 2.5° x 5° latitude-longitude box, TCCON XCO_2 (median) ±1h of overpass time, min. 50 good OCO-2 soundings, modified colocation criteria for city sites

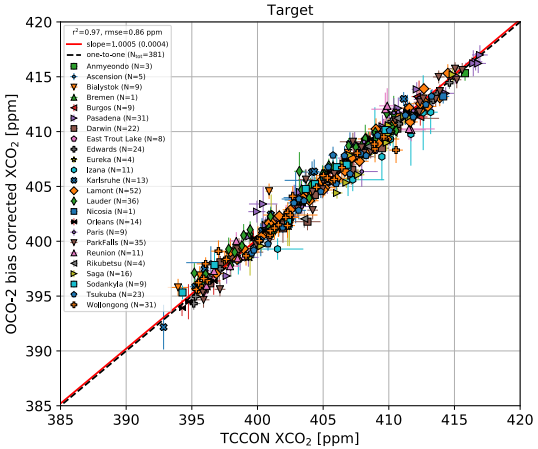


Comparisons to TCCON – Bias Corrected XCO_2

Statistics for mean overpasses

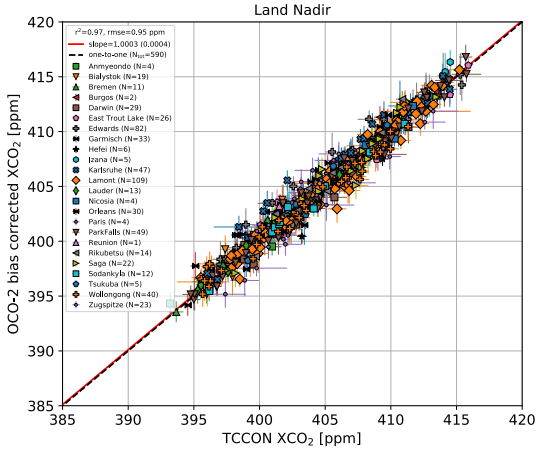
Target

N = 381, r^2 = 0.97
bias = 0.19 ppm
rms = 0.86 ppm



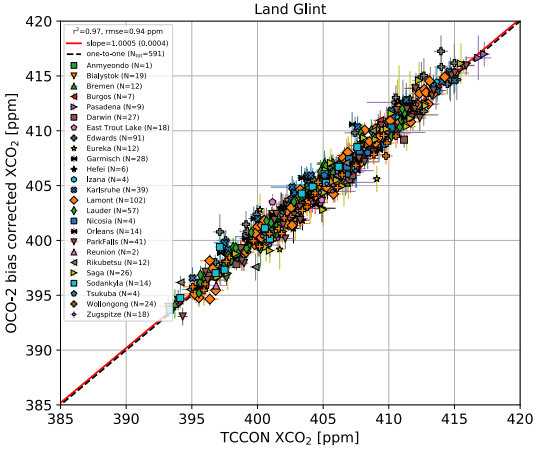
Land Nadir

N = 590, r^2 = 0.97
bias = 0.14 ppm
rms = 0.95 ppm



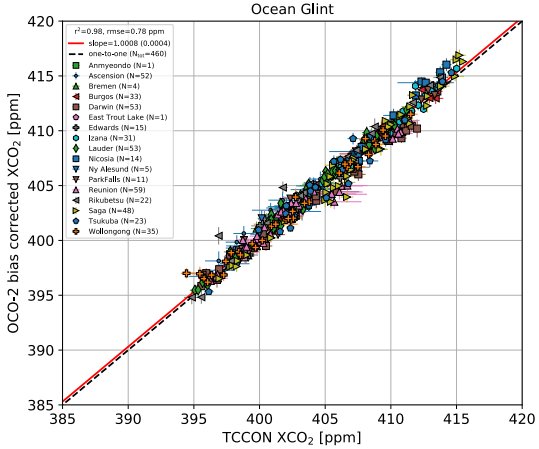
Land Glint

N = 591, r^2 = 0.97
bias = 0.17 ppm
rms = 0.94 ppm



Ocean Glint

N = 460, r^2 = 0.98
bias = 0.30 ppm
rms = 0.78 ppm



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bias = 0.17 ppm
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Ocean Glint

N = 460, r^2 = 0.98
bias = 0.30 ppm
rms = 0.78 ppm

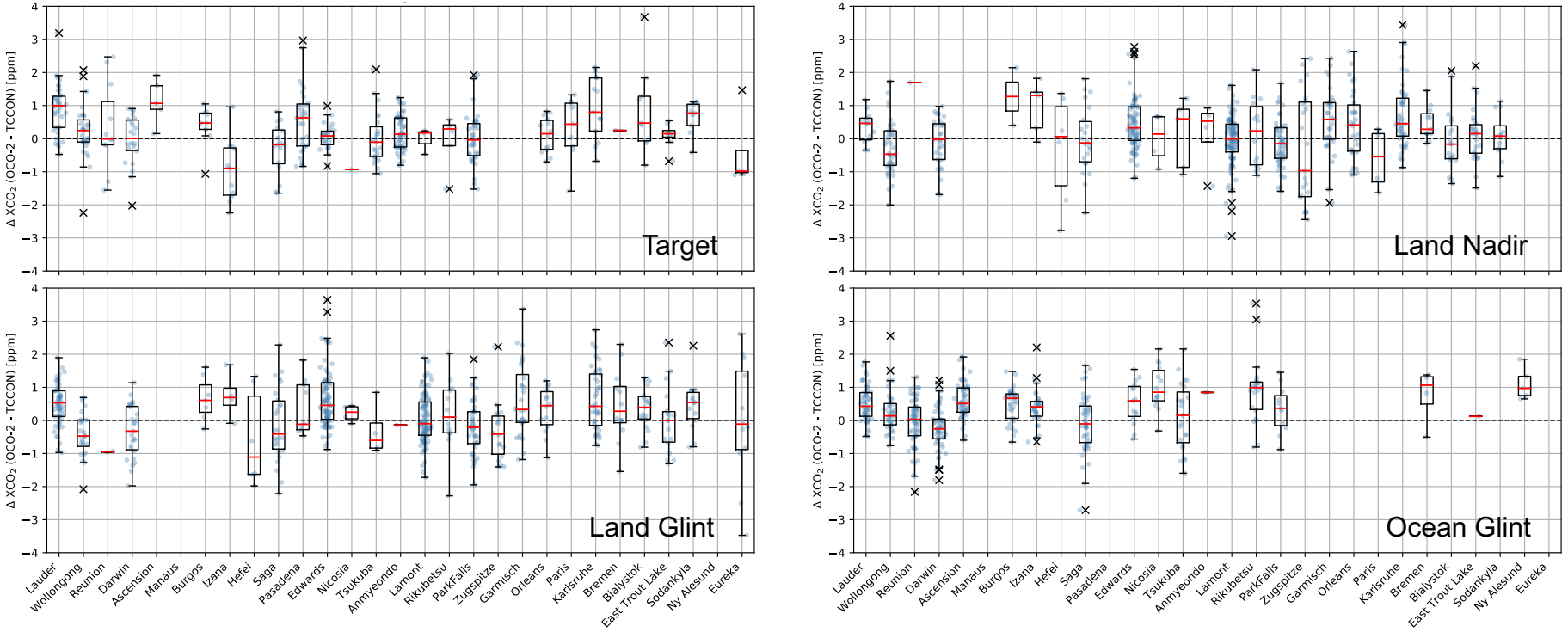
Comparisons to TCCON

Mode	N_{obs}	r^2	bias [ppm]	**V10 rms [ppm]**	**V9 rms [ppm]**
Target	381	0.97	0.19	0.86	0.92
Land Nadir	590	0.97	0.14	0.95	1.01
Land Glint	591	0.97	0.17	0.94	1.00
Ocean Glint	460	0.98	0.30	0.78	0.87

Statistics for mean overpasses

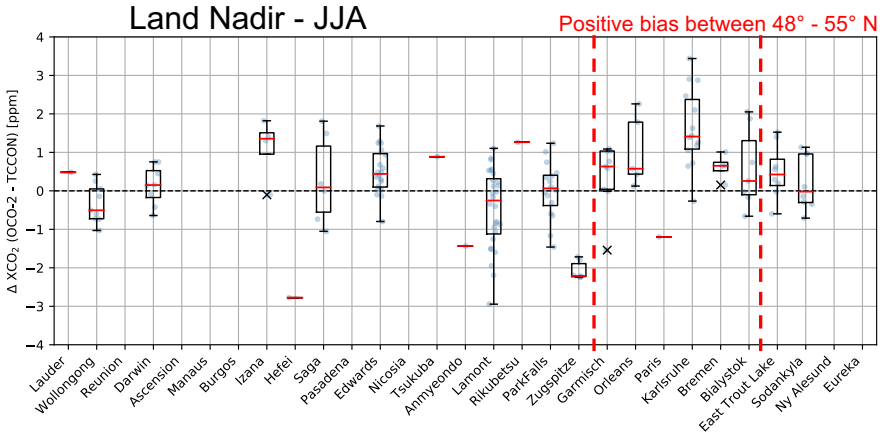
- Average bias over land 0.16 ppm and 0.30 ppm over ocean
- Bias mainly introduced by change of global scaling factor over time and stricter collocation criteria for ocean comparisons (compared to v10 development)
- Significant improvement of rms in v10 over v9 for all observing modes

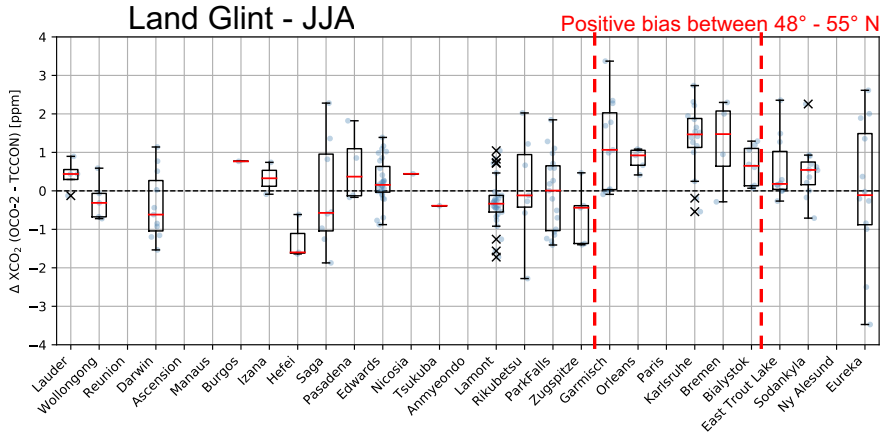
Comparisons to TCCON – Individual Sites



- Bias typically below 1 ppm for most sites
- Some sites exceed bias of 1 ppm; Izaña, Zugspitze (topography), Hefei (lack of data)

Comparisons to TCCON – Seasonal dependence

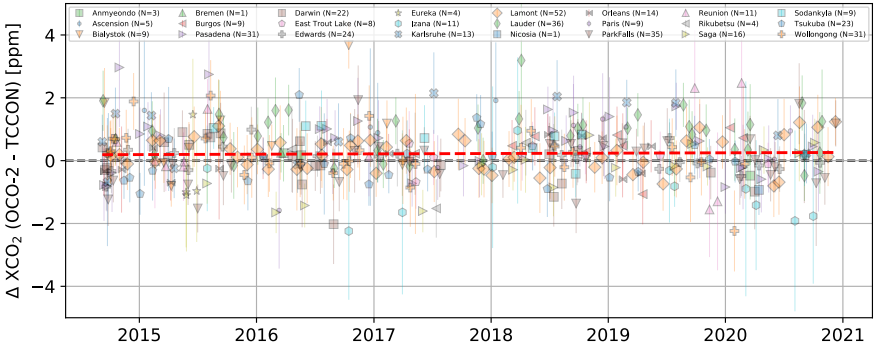




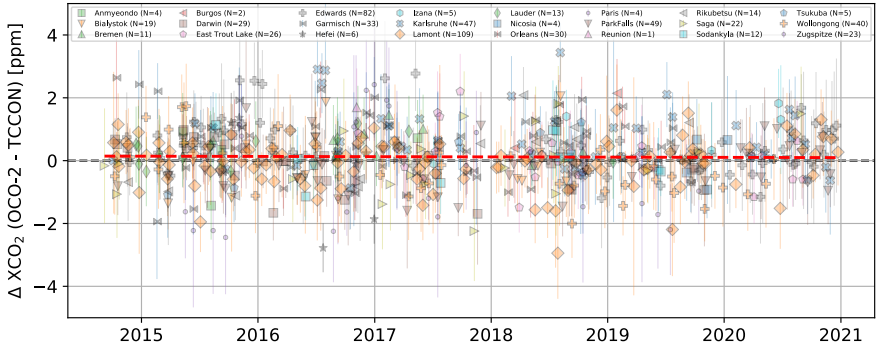
- No apparent seasonal bias for Ocean Glint and Target mode data
- Land nadir and land glint measurements indicate light positive bias over continental European sites during NH summer (average 0.75 ppm; single sites exceeding 1 ppm, e.g. Karlsruhe)

Time Trends

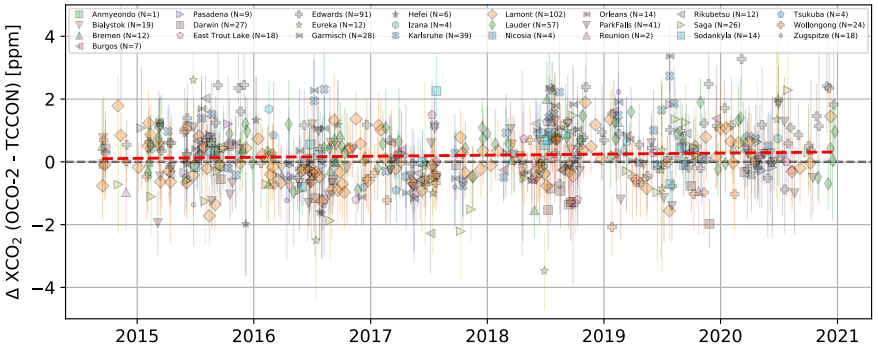
Target
slope: 0.01 ± 0.04 ppm/year



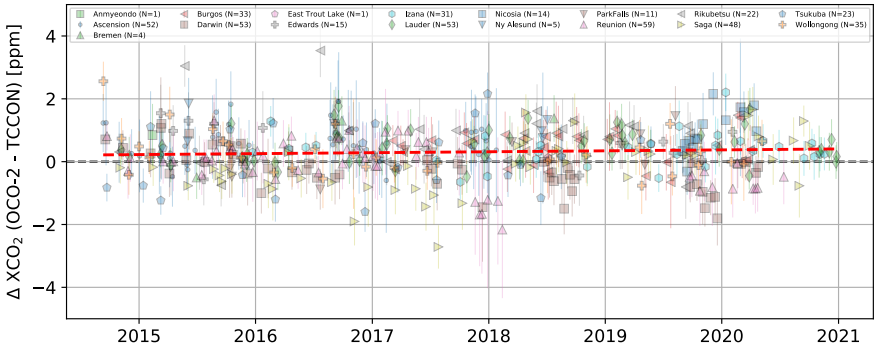
Land Nadir
slope: -0.01 ± 0.04 ppm/year



Land Glint
slope: 0.03 ± 0.04 ppm/year



Ocean Glint
slope: 0.03 ± 0.04 ppm/year



reported errors are 2*sigma

Time Trends

None of the methods above suggest a significant time drift in the data. OCO-2 V10 seems to fulfill requirements for remotely-sensed CO_2 products:

- < 0.2 ppm over some unspecified period: GCOS document 154, “Systematic Observation Requirements for Satellite based data products for climate”, 2011 update, page 33, product A.8.1.
- < 0.15 ppm/year: GCOS document 200, “Global Observing System for Climate: Implementation Needs”, 2016.
- < 0.2 ppm/year (Goal), < 0.5 ppm/year (Threshold): GHG-CCI User Requirements Document version 3.0.
- **These requirements are very generous, 0.01 - 0.02 ppm/year is probably more desirable.**

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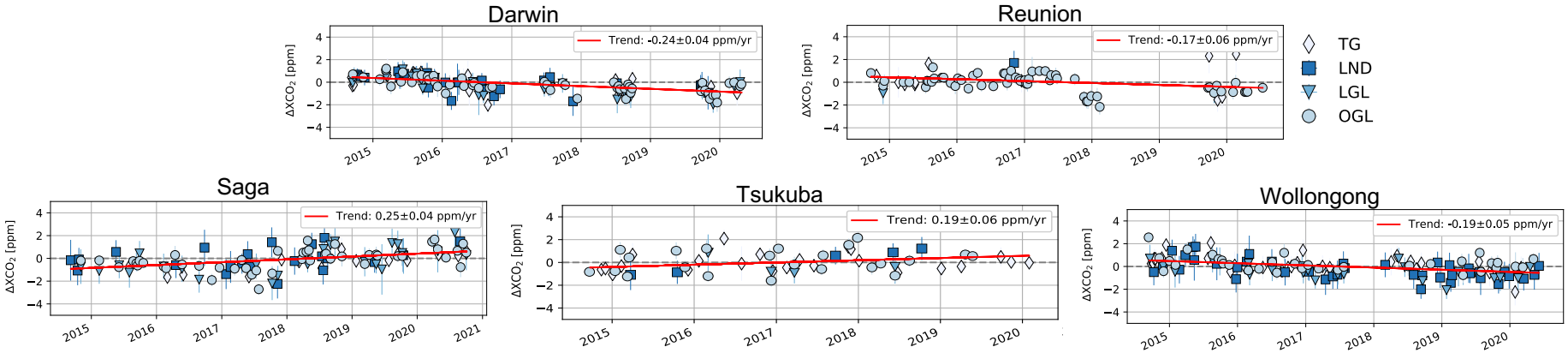
- **XCO_2 drifts are apparent over some individual sites: Darwin, Reunion, Tsukuba, Saga, Wollongong.**



Mean Growth Rate and Seasonal Cycle Amplitude

- The seasonal cycle of XCO_2 can be parameterized as a skewed sine wave with an upward trend (Lindqvist et al., 2015):

$$f(t) = a_0 + a_1 t + a_2 \sin\left(\omega\left[t - a_3\right] + \cos^{-1}\left[a_4 \cos\left(\omega\left[t - a_5\right]\right)\right]\right)$$

- The first two terms fit for a linear trend (average growth rate).
- $2*|a_2|$ denotes the peak-to-peak amplitude of the sine wave and is used to define the seasonal cycle amplitude.
- **The method cannot be used to quantify interannual variability but it gives an average seasonal cycle amplitude and an average growth rate pretty conveniently.**

For our analysis:

- Only possible if we combine OCO-2 data from all modes for individual sites, otherwise the temporal coverage is too sparse to make any statements about growth rate and seasonal cycle amplitude.
- Some additional OCO-2 requirements for a good fit:
  - Timeseries must cover at least three years with a minimum of two data points per year (for a good growth rate fit)
  - Minimum of three datapoints within ± 45 days of three local minima and maxima (for a good seasonal cycle fit)

Mean Annual Growth Rate

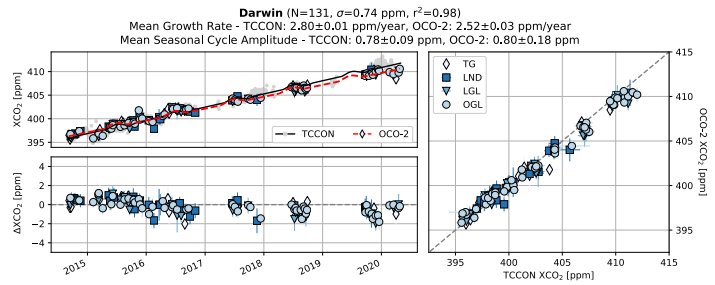
- For most sites, the mean annual growth rate agrees for TCCON and OCO-2 within 2*sigma.
- OCO-2 underestimate the mean annual growth rate for 10 sites by 0.0 – 0.3 ppm (~ 0.1 ppm).
- OCO-2 overestimate the mean annual growth rate for 8 sites by 0.0 – 0.2 ppm (~ 0.1 ppm).
- TCOON and OCO-2 mean annual growth rates disagree for Darwin, Saga, and Wollongong.

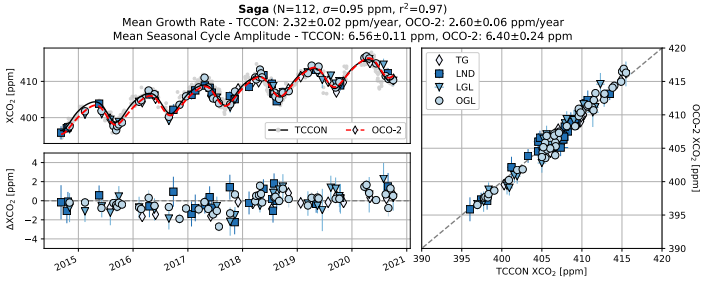
Mean Annual Growth Rate

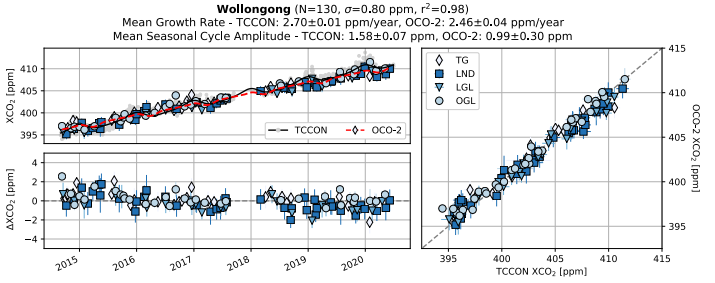
Site	TCCON [ppm]	OCO-2 [ppm]
Anmyeondo	---	---
Ascension	---	---
Bialystok	2.55 ± 0.04	2.60 ± 0.12
Bremen	2.58 ± 0.05	2.72 ± 0.24
Burgos	2.44 ± 0.03	2.40 ± 0.10
Pasadena	2.61 ± 0.01	2.50 ± 0.09
Darwin	2.80 ± 0.01	2.52 ± 0.03
East Trout Lake	2.50 ± 0.03	2.20 ± 0.17
Edwards	2.57 ± 0.01	2.53 ± 0.03
Eureka	---	---
Garmisch	2.45 ± 0.03	2.51 ± 0.09
Hefei	3.46 ± 0.25	---
Izana	2.37 ± 0.02	2.43 ± 0.09
Karlsruhe	2.48 ± 0.02	2.38 ± 0.06
Lamont	2.52 ± 0.01	2.52 ± 0.04
Lauder	2.43 ± 0.01	2.47 ± 0.03
Nicosia	---	---
Ny Alesund	---	---
Orleans	2.52 ± 0.02	2.42 ± 0.09
Paris	2.17 ± 0.05	---
ParkFalls	2.43 ± 0.02	2.51 ± 0.05
Reunion	2.70 ± 0.01	2.60 ± 0.05
Rikubetsu	2.46 ± 0.04	2.67 ± 0.14
Saga	2.32 ± 0.02	2.60 ± 0.06
Sodankyla	2.64 ± 0.02	2.70 ± 0.21
Tsukuba	2.59 ± 0.03	2.56 ± 0.11
Wollongong	2.70 ± 0.01	2.46 ± 0.04
Zugspitze	2.54 ± 0.03	2.49 ± 0.14

*reported errors represent 1*sigma

no statement possible
agree w/in 1*sigma
agree w/in 2*sigma
outside 2*sigma







Mean Seasonal Cycle Amplitude

- Fit function works best for NH sites
- For most sites, the mean seasonal cycle amplitude agrees for TCCON and OCO-2 within 2*sigma.
- OCO-2 underestimates the mean seasonal cycle amplitude over 12 sites (~ 0.3 ppm)
- OCO-2 overestimates the mean seasonal cycle amplitude over 7 sites (~ 0.6 ppm)
- TCOON and OCO-2 mean seasonal cycle amplitude disagrees for Lauder and Zugspitze.

Mean Seasonal Cycle Amplitude

Site	TCCON [ppm]	OCO-2 [ppm]
Anmyeondo	---	---
Ascension	---	---
Bialystok	8.45 ± 0.12	8.08 ± 0.60
Bremen	7.56 ± 0.19	6.46 ± 0.65
Burgos	5.63 ± 0.11	4.91 ± 0.44
Pasadena	5.42 ± 0.09	5.02 ± 0.67
Darwin	0.78 ± 0.09	0.80 ± 0.18
East Trout Lake	9.78 ± 0.10	9.44 ± 0.48
Edwards	5.46 ± 0.06	5.45 ± 0.20
Eureka	---	---
Garmisch	6.61 ± 0.14	7.00 ± 0.41
Hefei	7.53 ± 0.27	---
Izana	6.09 ± 0.07	6.72 ± 0.47
Karlsruhe	6.89 ± 0.12	7.02 ± 0.33
Lamont	5.63 ± 0.08	5.53 ± 0.21
Lauder	0.63 ± 0.04	1.83 ± 0.50
Nicosia	---	---
Ny Alesund	---	---
Orleans	7.01 ± 0.10	6.87 ± 0.37
Paris	7.61 ± 0.23	---
ParkFalls	9.25 ± 0.10	9.38 ± 0.31
Reunion	1.44 ± 0.07	1.40 ± 0.27
Rikubetsu	10.69 ± 0.21	11.03 ± 0.62
Saga	6.56 ± 0.11	6.40 ± 0.24
Sodankyla	10.17 ± 0.19	9.31 ± 0.30
Tsukuba	6.96 ± 0.16	7.64 ± 0.68
Wollongong	1.58 ± 0.07	0.99 ± 0.30
Zugspitze	5.39 ± 0.14	7.09 ± 0.54

*reported errors represent 1*sigma

no statement possible
agree w/in 1*sigma
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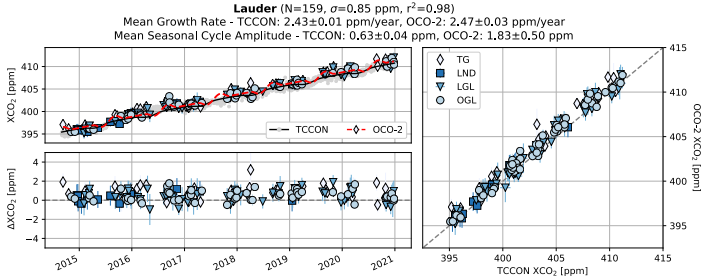
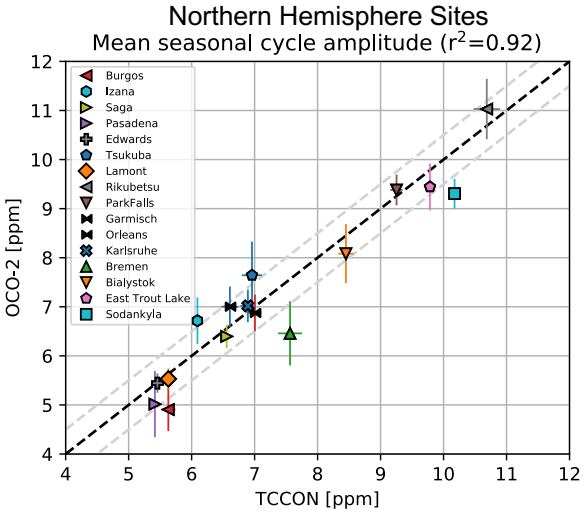
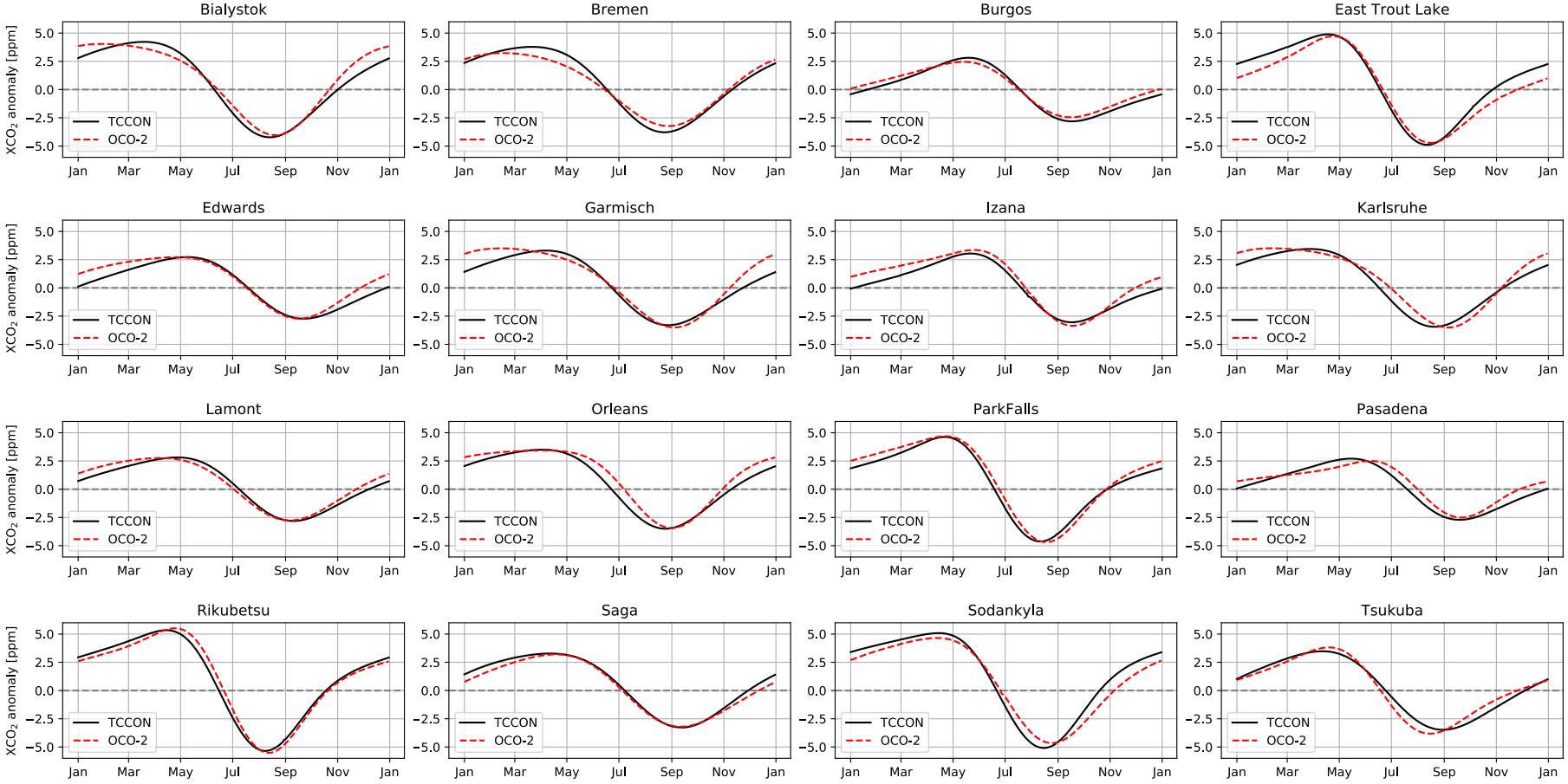
outside 2*sigma





Mean Seasonal Cycle Amplitude – Detrended (Northern Hemisphere)



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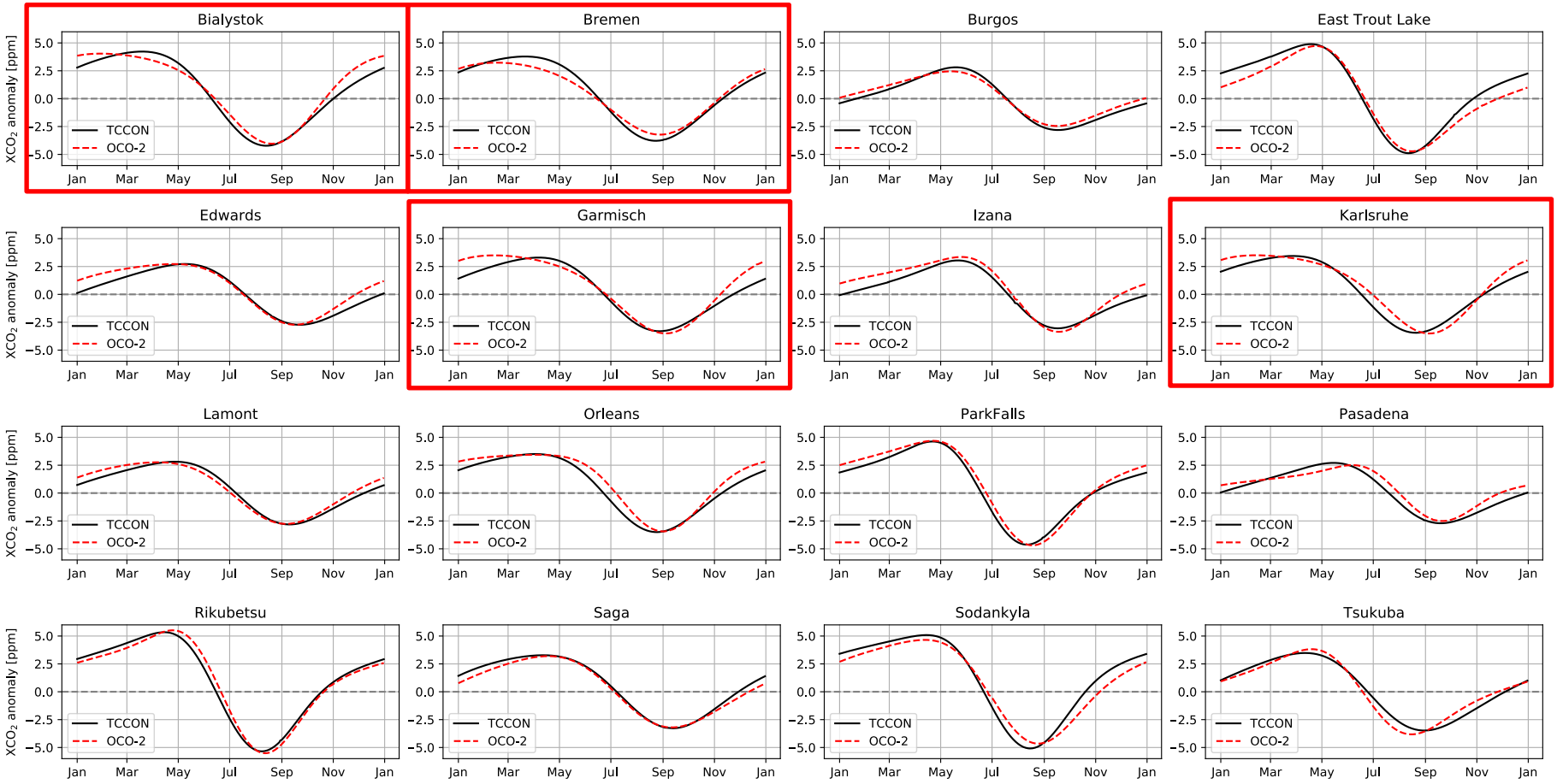

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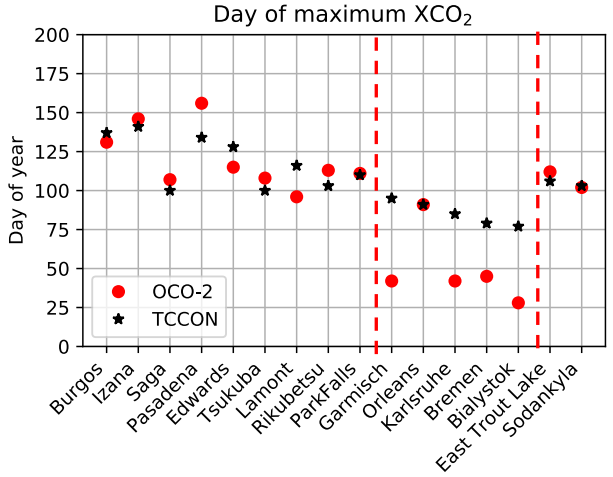

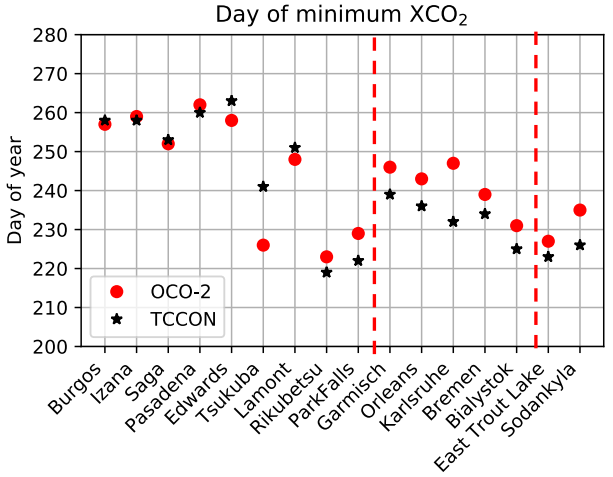

- For most NH sites, day of maximum XCO_2 for TCCON and OCO-2 within several days
- OCO-2 XCO_2 maximum early for European continental sites (~ 45 days)

- Range of days of minimum XCO_2 more restricted
- OCO-2 XCO_2 minimum late for European continental sites (~ 7 days)

High Level Summary

- Six year record of OCO-2 XCO_2 measurements (V10, Sept. 2014 – Dec. 2020). Same time period covered by TCCON with contributions from 28 sites (GGG2014 data record ended in Dec. 2020; no new GGG2014 data from now on).
- Overall good agreement against TCCON (bias over land 0.16 ppm and 0.30 ppm over ocean).
- Significant improvement of rms in v10 over v9 for all observing modes.
- OCO-2 appears biased high (~0.75 ppm) for LND and LG for continental European sites in NH summer
- No significant drift in XCO_2 against TCCON but drifts apparent over individual sites: Darwin, Reunion, Tsukuba, Saga, Wollongong.
- For most sites, the Mean Annual Growth Rate and Seasonal Cycle Amplitude for TCCON and OCO-2 agree within 2*sigma.
- OCO-2 underestimates the day of maximum XCO_2 over continental European sites (~ 45 days) and overestimates day of minimum XCO_2 (~ 7 days)

THANK YOU!

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Additional Slides

Comparisons to TCCON – Seasonal dependence